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Biochar and managed perennial ecosystems: Testing for synergy in ecosystem function and biodiversity

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Abstract
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Disciplines
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$35,973 for year one
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$33,567 for year three

Q What are the best use practices for biochar in natural systems?

ECOLOGY

A By investigating biochar's effect in a mixed community of native prairie species under field conditions, the researchers can determine the potential effects of accidental exposure during agricultural applications. Through small controlled experiments, they can clarify the mechanism behind these observed effects.

Background

Biochar is a carbon-rich material similar to charcoal. It is produced when biomass is burned in the absence of oxygen, a process known as pyrolysis. Pyrolysis and the production of biochar currently are being promoted as a means to produce domestic fuel (bio-oil) while concurrently producing a co-product that increases crop yield and sequesters carbon in the soil (biochar). While there may be many potential benefits in the application of biochar to agricultural soils, such as enhanced soil fertility and improved soil water status, there are no studies of higher order ecological and ecosystem effects of biochar and its potential synergistic interactions (either positive or negative) on complex perennial systems. In this study the researchers address this research gap in two ways: a field experiment focused on ecosystem effects and smaller lab experiments to investigate underlying mechanisms. They address biochar impacts on four ecosystem components: soil nutrients, water, plants and soil organisms.

Project objectives were to:

1. Determine the direct effects of biochar on ecosystem structure and function in perennial communities
2. Identify the key mechanisms of biochar interaction on the relationship between plants and co-occurring organisms
3. Conduct a meta-analysis on biochar's effect on plants, soil nutrients and organisms

Approach and methods

The commercial availability of biochar was very limited when the project began. The researchers were able to find enough Royal Oak Biochar, which was made from hardwood sources, through connections in the ISU Horticulture Department. The Royal Oak Biochar was used in both field and lab studies. They also had a small supply of Interra Biochar and CQuest Biochar, which also were made from hardwood sources.

For objective 1, the research team established a field-based experiment at Iowa State University's Western Research Station near Ute, Iowa. They chose a brome-dominated grassland, and the vegetation was removed prior to setting up the experiment.

Prairie plots at the Western Agricultural Research Station, summer 2013.

They established five experimental blocks each containing six 4-m2 plots (30 total plots). Within each replicate block, they randomly assigned plots to one of six nutrient treatments using manure and biochar. After the biochar and manure were incorporated into the soil, the seedbed was firmed and the entire field was planted with a diverse prairie mixture containing 30 tall grass prairie species. Variables studied included percent of plant cover (legumes considered separately), species richness, root biomass and mycorrhizal colonization, soil phospholipid fatty acid and other enzymatic assays, and a wide variety of soil nutrient measures including organic and total carbon and total nitrogen. Sampling was conducted at randomly selected 0-10 cm depths.

Under objective 2, the PIs directed undergraduate research projects. Erich Sneller used both field and lab experiments to compare biochar and mycorrhizal inoculation use in small-scale production of cherry tomatoes. Britteny Ross investigated the physical and chemical properties of three biochars (CQuest, Interra and Royal Oak) used in the experiments. She tested for stability, dehydration and degree of carbonization (the most common industry metrics to indicate "beneficial" biochars). Atomic ratios and elemental analyses and a root study also were conducted.

Objective 3: There is a growing body of literature concerning biochar. Unfortunately, there is little consensus on the effectiveness of this material for improving crop yield and maintaining soil fertility because of variability in the studies. To make sense of the growing literature available, the researchers performed a meta-analysis, or a summary analysis of many published studies, which can help identify trends or patterns that may not be evident in a single study. In this case there were 114 published articles that met the team criteria for inclusion in the meta-analysis.

Results and discussion

Field Experiment

- Overall, the biochar treatments had a limited effect. The interaction of manure and biochar did not provide any clear trends.
- Total plant cover of biomass was not affected by the biochar or manure treatments, although the legume portion of biomass was positively affected.
- The 3 percent biochar treatment improved the establishment of planted species (as measured by their proportion of biomass) and increased plant diversity and evenness.
- Manure application affected phosphorus cycling (phosphorus content in plant tissue and the activity of the soil enzyme acid phosphotase). The interaction of manure and biochar affected soil phosphorus.
- The soil microbial community was largely unaffected by the biochar and manure treatments.
- Plant nutrient content (such as N, P and K) had variable responses to treatments.
- Field oil pH and bulk density showed no treatment response.

The scientists evaluated ecosystem responses to biochar application with a meta-analysis of 114 published manuscripts. Among the findings:

- Despite variability introduced by soil and climate, the addition of biochar

to soils resulted, on average, in increased aboveground production, crop yield, soil microbial biomass, rhizobia nodulation, plant K tissue concentration, soil P, soil K, total soil N, and total soil C compared with control conditions.
- Soil pH also tended to increase in soils with added biochar.
- Variables that showed no significant mean response to biochar included belowground production, the ratio of aboveground: belowground biomass, mycorrhizal colonization of roots, plant tissue N and P concentration, and soil inorganic N.
- There was no detectable relationship between the amount of biochar added and aboveground production and soil pH, although the mean response was positive for application rates between 0.5 and 5 percent.

Tomato study

This study examined the benefits and risks associated with biochar and mycorrhizal inoculation for cherry tomatoes, a small-scale horticultural crop. Results from this study:

- Biochar and soil inoculation did not result in benefits to the development of the tomato seedlings in the growth chamber.
- Biochar significantly reduced plant tissue N.
- Biochar increased soil organic carbon and total soil nitrogen. It reduced soil P.
- Soils with biochar had significantly higher pH.
- Biochar, but not soil inoculation, affected colonization of mycorrhizae at plant harvest. Biochar significantly reduced root colonization.

Erich Sneller, an undergraduate, conducted this project as his ISU senior honors project. It was done in conjunction with Table Top Farm near Nevada, Iowa.

Biochar analysis

Interra Biochar was shown to exhibit the most optimal characteristics for nutrient contribution and water retention.

Root experiments

There was considerable variability among trials and species. The lack of consistent trends did not allow the researchers to make any generalizations

Aquaculture experiments

The post-doctoral student in the lab who was to perform these left before this project could be completed. These monies were used for more root experiments and biochar characterization studies

Conclusions

Both the field experiments and quantitative review examining the effects of biochar on multiple ecosystem functions found that the addition of biochar generally improves, or at least does not harm, many aspects of the ecosystem and its functioning, including plant production and soil nutrient content. This is consistent with the findings of other non-quantitative reviews.

However, to achieve meaningful goals for carbon sequestration, such as 19 percent of current anthropogenic CO_2 emissions, biochar would have to be applied to a significant portion of the earth's arable land. Nontarget organisms will be affected by this activity, but there are limited data available for biochar's effects on non-agricultural species, including native plant communities, aquatic systems, and soil organisms such as rhizobia. These organisms perform many critical ecosystem services (such as erosion prevention and pest predation) in agricultural systems. It is critical to understand how biochar interacts with all aspects of the environment prior to its widespread application.

Impact of results

The meta-analysis of biochar papers prepared for the project was among the top 15 downloaded papers in *Global Climate Change-Bioenergy* in both 2013 and 2014.

Education and outreach

This project resulted in two peer-reviewed publications (and three others are being prepared).

- Biederman and Harpole. 2013. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *Global Climate Change-Bioenergy* 5: 202-2014.
- Harpole and Biederman. 2014. On the importance of accurate reporting: a response to comments on 'Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis' *Global Climate Change-Bioenergy* 6:172-175
- Biederman LA, Harpole WS. 2013. Biochar has mixed effects on prairie resto ration. Ecological Society of America annual meeting, Minneapolis, MN.

Interviews: Biederman at KMA radio (November 2012) and *Iowa State Daily* (http://www.iowastatedaily.com/news/article_10b8f6e4-3ca4-11e2-9dcb-001a4bcf887a.html).

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